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TITLE: Ultrasound imaging system and method for improving resolution and operation

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Detailed Description Text (5):
As with conventional ultrasound systems, this system 110 performs ultrasonic visualization, the well-known interrogating-and-imaging process which includes ultrasound generation, ultrasound detection, image reconstruction, and image presentation phases. During the ultrasound generation phase, the transmit beamformer 125 applies multiple signals to elements of a transducer array 135 to cause the elements to vibrate and emit ultrasonic energy to a tissue. Next, in the ultrasound detection phase, the receive beamformer 130 measures the signals created by the transducer array 135 when ultrasonic energy reflected by the structures in the tissue impinge on the transducer array 135.

Detailed Description Text (6):
The signals generated by the receive beamformer 130 are channeled to the scan converter 175 for image reconstruction. During this phase, the scan converter 175 processes the detected signals to create an image, which is presented on the display 185 during the image presentation phase. Additionally, the image can be stored in the image memory 180.

Detailed Description Text (28):
Temporal resolution can also be improved by using a different persistence level inside the region of interest than outside the region of interest. Persistence inside the region of interest can be a function of image motion. As used herein, the term "image motion" refers to motion within an ultrasound image such as, but not limited to, tissue motion and motion of contrast agents. As described in more detail below, motion can be detected by using motion estimates of a sub-block of moving pixels or by computing the difference between pixels at the same spatial location in successive frames. If there is significant image motion, it is preferred that persistence be reduced to avoid smearing or blurring of the moving object. Similarly, if there is very little image motion, it is preferred that persistence be increased to average out noise in the image, thereby increasing signal-to-noise ratio. As discussed below, persistence inside the region of interest can be varied using the techniques of motion-compensated persistence with motion-compensated interpolated frames, motion-compensated persistence with real ultrasound frames, and motion-adaptive persistence.

Detailed Description Text (30):
Another way in which persistence inside the region of interest can be varied is by using motion-compensated persistence with real ultrasound frames. This technique is similar to the first technique described above in that motion vectors can be computed for different parts of the image, but instead of generating a motion-compensated interpolated frame, the persistence filter determines which pixels to process. That is, in the first technique, motion estimates are used to create motion-compensated interpolated frames to align moving objects in an image. The

persistence filter in the first technique processes pixels corresponding to the same spatial location across a number of frames. In this technique, the spatial locations employed by the persistence filter are determined by the motion estimates. That is, motion estimates are used to determine the location of a moving block of pixels, and that location is used by the persistence filter. In this way, pixels that belong to the same object are filtered. When there is no motion is present, the filter uses the same spatial location, as in the case of a conventional persistence filter. As with the first technique, this technique provides the advantages of reducing blur and of reducing noise in the same amount in both moving and non-moving areas of the image. Because motion estimates employed in this technique, the same motion estimates can be used to generate motion-compensated interpolated frames, thereby reducing computation time by avoiding recomputation of motion estimates.

Detailed Description Text (34):
In using motion-adaptive persistence, the persistence filter coefficient .alpha.(n) varies as a function of image motion. Specifically, the persistence filter coefficient .alpha.(n) increases as the level of motion within the region decreases. FIG. 4B illustrates such a relation for three different filter designs 492, 494, 496, although others designs can be used. As shown in FIG. 4B, the persistence filter coefficient .alpha.(n) increases as d decreases. The function d can be computed by using motion estimates of a sub-block of moving pixels or by computing the difference between pixels at the same spatial location in successive frames. The function d preferably is derived from motion estimates of sub-blocks of pixels determined to give the best match between a region in the previous frame O (n-1) and the current image frame I(n). This motion vector is the value (x,y) which gives the minimum sum of absolute differences and may be derived at high speed using a L64720A motion estimator or a similarly programmed TMS320C80 processor. Technically, the net motion length is the square root of (x.sup.2 +y.sup.2), where x and y are the pixel shifts required to obtain the best match.

Detailed Description Text (35):
An advantage of this implementation is that the sum of absolute differences is an error signal related to noise in the image. If the detected motion is small or varies randomly between sequences and the sum of absolute differences is larger than a threshold, the image is probably stationary and noisy. Persistence could then, accordingly, be increased.

Detailed Description Text (36):
As mentioned above, the function d can also be computed by computing the difference between pixels at the same spatial location in successive frames--an indication of image movement. That is, if motion is present, it is likely that the pixel values will change from frame to frame. Specifically, the function d can be given by the following equation: ##EQU1## wherein I(n,x,y) comprises an intensity value of a pixel in the current ultrasound-image input frame, O(n-1,x,y) comprises an intensity value of a pixel in a previous ultrasound-image output frame, and "(x,y) in A(i,j)" comprises every pixel (x,y) in an area A(i,j) in the selected region of interest. It is important to note that other equations can be used to represent the function d.

Detailed Description Text (39):
There can be situations in which the value of d is high even though most pixels in the region are below a certain intensity value. Such a situation arises due to noise in the region, not object motion. If the minimum-sum-of-absolute-differences method is used, situations in which d is small or randomly varying and the sum-of-absolute differences is large indicate noise and little motion. In these situations, the persistence filter coefficient .alpha.(n) can be assigned a high value to average out the noise, thus improving the signal-to-noise ratio for the region.

Detailed Description Text (52):
To form a spatially smooth composite image, a smooth transition can be created between the first and second image portions. A smooth transition can be formed by summing a fraction of the first image portion with a fraction of the second image portion at the boundaries of the region of interest. Referring now to FIG. 5, preferably, in the region 530, the pixel locations closest to region 510 are determined by a weighted sum of image data from the first and the second image data, wherein the first image data is emphasized, while at a location closest to region 520, the second image data is emphasized (i.e., linear interpolation of the first and second data depending on position). Another way to spatially smooth the composite image is to apply a low-pass filter (for example, within four pixels from the boundary) to reduce artifacts. Additional artifact reduction methods are described below.

Detailed Description Text (62):
To measure motion, the motion estimator 955 performs an image tracking operation to find estimated pixel motion of a selected sub-block of pixels from image frame N to image frame N+1. To measure motion, the motion estimator 955, which preferably includes a L64720A motion estimator from LSI Logic, performs a minimum-sum-of-absolute differences operation, as is well known in the art. Alternatively, a high power, programmed digital signal processing circuit, such as a TMS320C80 circuit by Texas Instruments, can be used.

Detailed Description Text (65):
As an example, consider the situation in which one interpolated frame is to be generated and the motion estimator 955 determines that a 32.times.32 sub-block of pixels (initially located at locations (0-31, 0-31) in image frame N) moved 8 pixels to the right and 8 pixels down. Because only one frame will be inserted, the factor used by the motion scaler 965 is 0.5. Accordingly, the scaled motion estimate is 4 pixels (0.5*8) to the right and 4 pixels (0.5*8) down. Thus, the pixel sub-block will be placed at locations (4-35, 4-35) in the interpolated frame. As discussed further below, it is also possible to add a component due to the N+1 frame. In this case, the required motion is 4 pixels to the left and 4 pixels up, so that, theoretically, the interpolated frame N and frame N+1 are superimposed.

Detailed Description Text (67):
Another problem which can arise when sub-blocks are moved is that there can be pixel locations in the interpolated image frame that do not contain new pixel data (i.e., "holes" are formed in the interpolated image frame). One approach to dealing with holes is to eliminate the possibility of their creation. That is, sub-blocks can be written over a copy of a real image frame (e.g., image frame N or image frame N+1). In this way, there will always be pixel information at every pixel location of the interpolated image frame even if some locations in the interpolated image frame do not contain new data. Another approach is to fill the holes with pixel information interpolated from surrounding sub-blocks.

Detailed Description Text (70):
Another advantage is that this method permits the use of lower channel cable counts in situations where high channel counts would otherwise be required. For example, phase-aberration corrected images may require very high physical transducer element counts in 1.5 or 2 dimensional arrays. Since cable costs (and termination costs in particular) can be prohibitively expensive, a potential option is to multiplex, for example, half the array in one firing and the other half in the next firing. This multiplexing can be performed on a line-by-line basis rather than a frame-by-frame basis and is preferably performed by using multiples of the HV2xx family of multiplexers from Supertex, Inc. (Sunnyvale, Calif.) or other suitable circuitry. With this multiplexing, not only is the cable channel count halved, but the frame rate is also halved. By using the method of this preferred embodiment, full apparent frame rate can be achieved even with using lower channel cable counts. Additionally, this method can be used in a three-dimensional volume scan from a

two-dimensional array where frame rate will be very slow.

Detailed Description Text (72):
While the above method has been described in terms of scan-converted images, the motion estimations can be applied to raw acoustic line data (envelope detected, RF, or baseband In phase/Quadrature data), using the known geometry of the lines (e.g., polar) to convert to required pixel translations (i.e., Cartesian). However, the method described above is preferred on the grounds of simplicity.

Detailed Description Text (87):
The controller 1115 of this system 1110 can additionally comprise means for automatically altering the operation mode of the transducer array 1135 in response to an absence of detected image motion. As mentioned above, the motion estimator 1160 can identify motion in the image, typically by measuring motion of a sub-block of pixels between two ultrasound-image frames using, for example, a minimum-sum-of-absolute-differences operation. Zero motion between successive frames indicates that the probe containing the transducer array 1135 is not in use.

Detailed Description Text (94):
FIG. 14 is a flow chart of a method for generating a distortion-corrected image inside a region of interest in response to measured image or transducer motion. First, transducer or image motion is measured (step 1410). In response to the measured motion, the controller 1315 can estimate the effect of the measured motion on line spacing and automatically reprocess line data with corrected line spacing (step 1420). Additionally, the controller 1315 can reposition sub-blocks of pixels in the ultrasound-image frame in response to measured motion (step 1430).

Detailed Description Text (98):
Another type of image motion-related distortion is caused by time delay between lines acquired on the left and right hand side of the image frame. The controller 1315 can automatically reposition sub-blocks of pixels in the ultrasound-image frame (step 1430). As an example, suppose sub-block P (which in this example is a single pixel) is located at position X1 in the first acquired frame (FIG. 15) and at position X2 in the second acquired frame (FIG. 16). By a scan line's lateral position, the controller 1315 can calculate when pixels were acquired in a frame. In this example, in the first acquired frame, the left-most scan line was acquired at time T0, sub-block P was acquired at time T1, and the right-most scan line was acquired at time T2. In the second acquired frame, the left-most scan line was acquired at time T3, sub-block P was acquired at time T4, and the right-most scan line was acquired at time T5.

Detailed Description Text (105):
In the preferred embodiments described above, transducer or image motion is measured. The general field of motion measurement between successive image frames has been discussed widely in the public literature (see Image Sequence Analysis, T. S. Huang (Editor) Springer-Verlag, 1981 and "Interframe Interpolation of Cinematic Sequences," Ribas-Corbera & Sklansky, Journal of Visual Communication and Image Representation, Vol. 4, No. 4, December 1993 (pages 392-46)). While any means of motion measurement can be used, it is presently preferred that a motion estimator employing a Moving-Picture-Experts-Group (MPEG) standard be used to track the movement of a block of pixels between image frames. While MPEG applies to both video and audio, only video (specifically, the luminance component) is relevant here. It is preferred that a L64720A motion estimator from LSI Logic be used.

Detailed Description Text (106):
An MPEG motion estimator calculates, in real time, motion vectors for a blocks of pixels moving from one image frame to the next. It is preferred that the ultrasound image be split into 32.times.32 or 16.times.16 macroblocks. Between successive input frames, a best fitting motion estimation is made for each block, preferably using a sum of absolute differences in pixel intensity. Other techniques can also

be used. An error between the two blocks corresponding to the degree of correlation can also be calculated. The vector shifts and error components are then coded for transfer.

Detailed Description Text (117):
In addition to scan-converted, rectangular acoustic grids, motion estimates can be applied to RF (raw acoustic line) data. In this context raw acoustic line data means any of true RF, IF, or baseband In phase/Quadrature data. Motion estimates on RF data for blood speckle tracking are known in the art (see "A Novel Method for Angle Independent Ultrasonic Imaging of Blood Flow and Tissue Motion," L. N. Bohs, IEEE Trans, BME Vol. 38, No. 3, March 1991, pp. 280-286). If RF data frames are used to produce an interpolated "raw acoustic line data frame," distortions due to the fact that the lines are not in a rectangular format may cause only minor problems. However, it should be noted that in the case of sector- or Vector.RTM.-type format, motions appear to be larger at the top than at the bottom due to the high line density at the top of the image. For example, for a given azimuthal translation, five lines are crossed at the top of the image, while only three lines are crossed at the bottom of the image. Accordingly, if the RF image data is motion estimated, it is preferred that the data is sampled at least twice per RF period.

CLAIMS:

60. The method of claim 58, wherein a difference between pixels at a same spatial location in successive frames is used to measure motion.

67. A method for generating a persistence filter coefficient of a region in an ultrasound-image frame comprising the steps of:

(a) measuring image motion in an area of a region using at least two ultrasound-image frames; and then

(b) applying a persistence filter coefficient for the region as a function of the measured motion in step (a), said function comprising a relationship wherein the persistence filter coefficient increases as the difference in pixel intensity decreases.

94. The method of claim 85, wherein step (c) comprises the step of averaging pixel data in a location in the motion-compensated interpolated image which comprises overlapping data.

96. The method of claim 85, wherein step (c) comprises the step of writing interpolated pixel data in a location in the motion-compensated interpolated image free of new pixel data.